# Introduction to Mu2e Target, Heat Shield and Beam Absorber

CD1 Internal Review
December 6, 2010

R. Coleman

# Mu2e*

- Mu2e is designed to search for the coherent conversion of a $\mu^-$ to an $e^-$ in field of a nucleus.
  - No emission of neutrinos
  - Coherent conversion: nucleus remains intact
  - Signature is a mono-energetic 105 MeV electron.
- This would be an example of *charged lepton flavor violation*, which has never been observed.
  - Related to neutrino oscillations
  - Allowed in the Standard Model, but the rate is essentially zero ($< 10^{-50}$)
  - Charged lepton flavor violation can only be observed in an experiment if it is mediated by new physics that is beyond the Standard Model.
    - SUSY, extra dimensions, composite quarks, etc

* Thanks to Ron Ray for many of introduction slides Doc-db 960

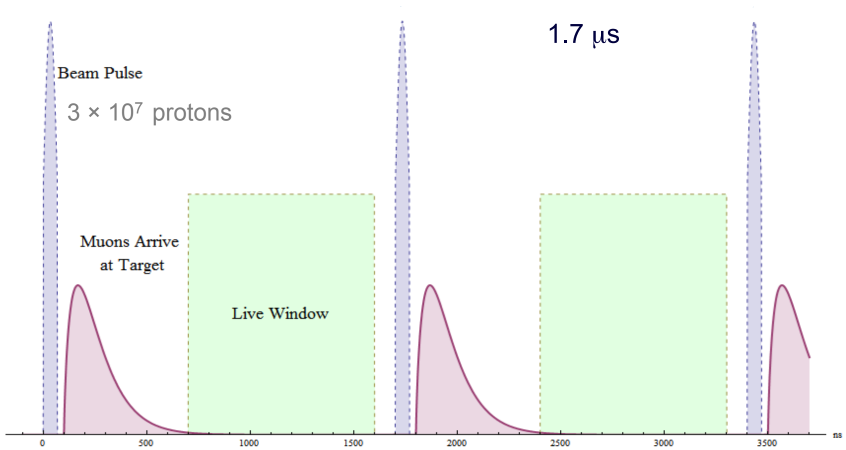
# Mu2e Sensitivity

- Single event sensitivity = $2 \times 10^{-17}$

$$R_{\mu e} = \frac{\mu^- + A(Z,N) \rightarrow e^- + A(Z,N)}{\mu^- + A(Z,N) \rightarrow \nu_\mu + A(Z-1,N)},$$

- For $10^{18}$ stopped muons
  - If $R_{\mu e} = 10^{-15}$ we will observe ~ 50 events
  - If $R_{\mu e} = 10^{-16}$ we will observe ~ 5 events
- Expected background < 0.5 event
  - Assumes $2 \times 10^7$ s of running
  - 4 x $10^{20}$ protons on target @ ~2 E13 per s
- Expected limit = $6 \times 10^{-17}$ (90% C.L.)
  - Best existing limit is $6 \times 10^{-13}$ (90% C.L.) from SINDRUM II

# Experimental Technique



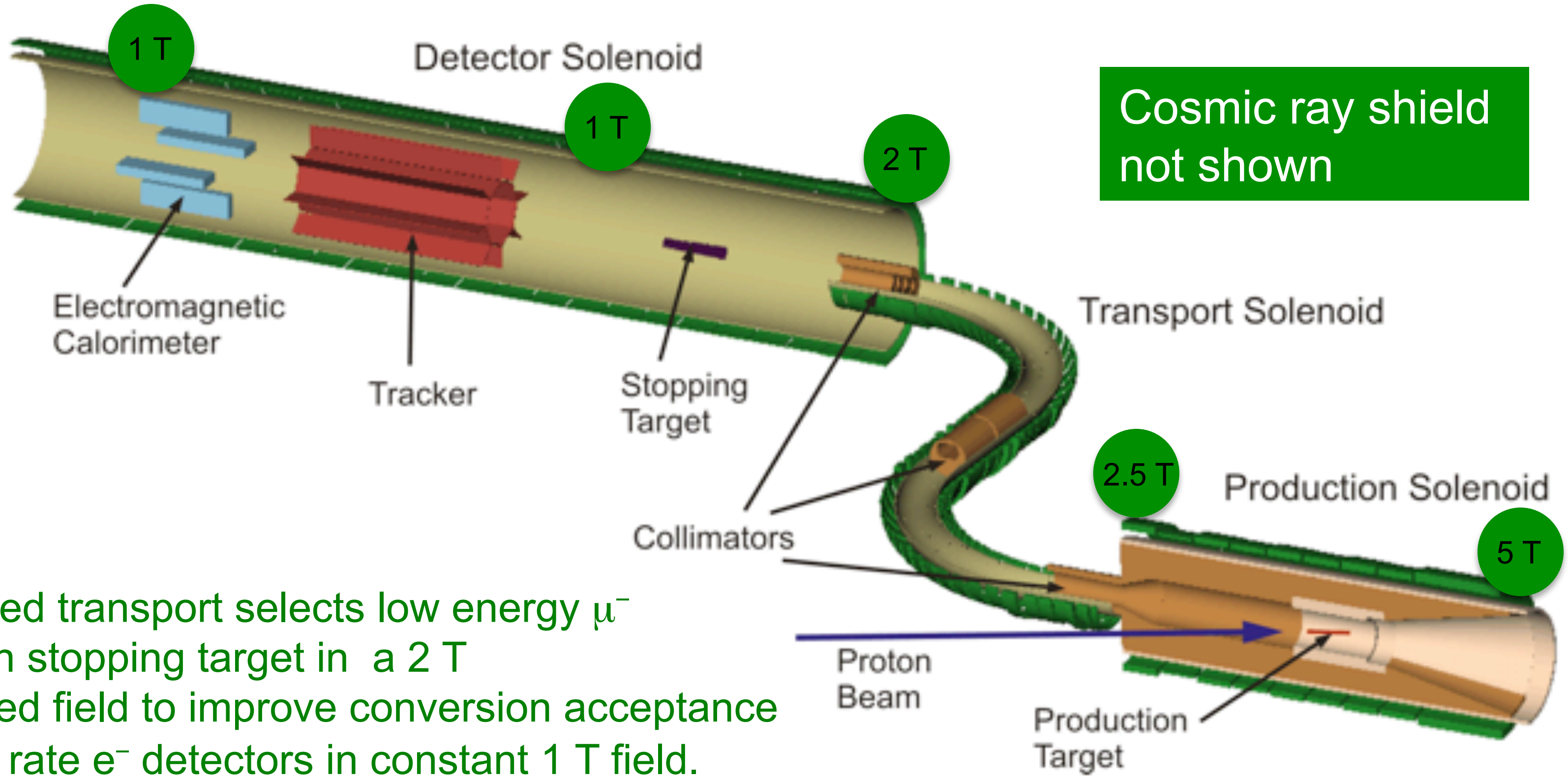

Don't want proton beam between pulses

- Divide Booster batches of $4 \times 10^{12}$ protons into micro-bunches of $3 \times 10^{7}$ separated by 1-2 muon lifetimes
  - Revolution time in Fermilab pbar source is 1.7 $\mu$s. Perfect!

- Stop ~ $10^{10}$ $\mu^-$ per Booster batch in an aluminum target. Make muonic Al. Lifetime: 864 ns
- Wait 700 ns for prompt backgrounds to clear- crucial to improved sensitivity over previous experiments
- Improved muon collection with solenoid scheme

# Mu2e Detector

- High Z target to maximize pion production
- Graded 5T field to maximize pion capture




Cosmic ray shield not shown

- Curved transport selects low energy $\mu^-$
- Muon stopping target in a 2 T graded field to improve conversion acceptance
- High rate $e^-$ detectors in constant 1 T field.

Vacuum $10^{-4}$ torr

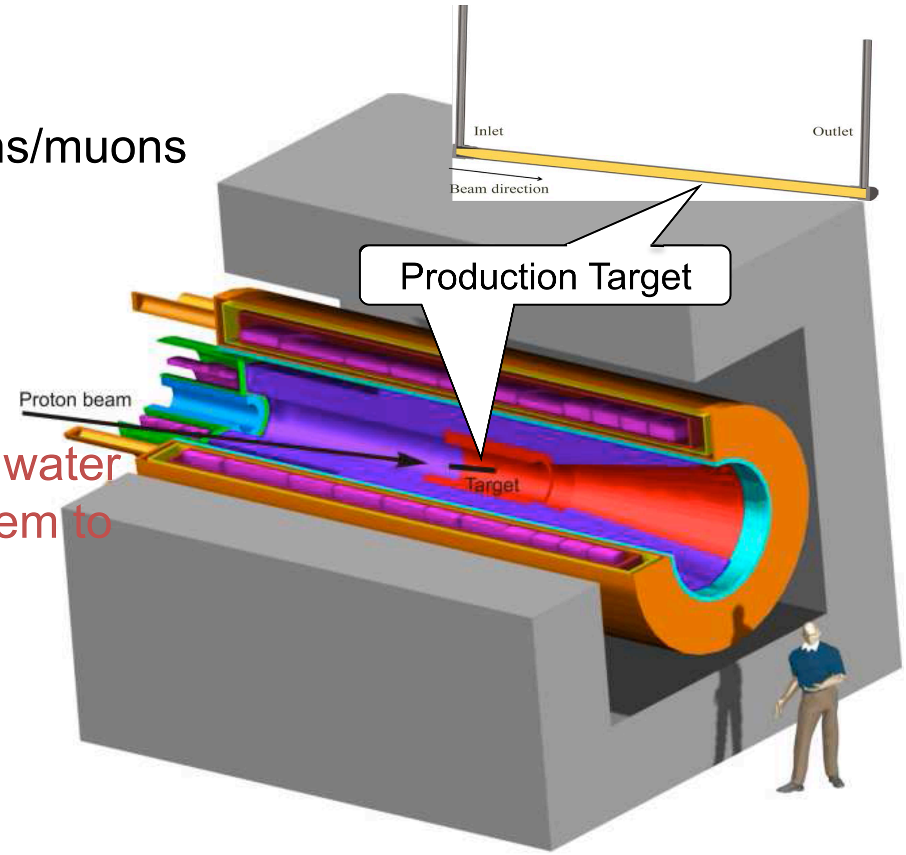
# History & Status

- MECO proposal for AGS at Brookhaven 1999.
- MECO canceled in 2005 mainly due to AGS cost & transition to nuclear physics program
- DOE/P5 10 yr report recommends Mu2e proceed under all budget scenarios in May 2008
- Mu2e proposal submitted in October 2008
- Mu2e received CD-0 in November, 2009
- We are aiming for CD-1 by June of 2011.

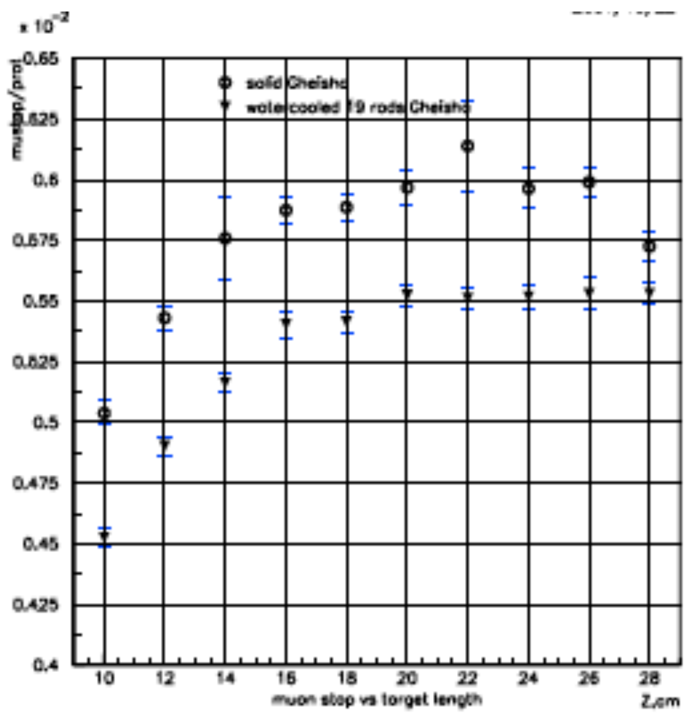
# Production Target

- Production Target
  - Water-cooled gold target in titanium jacket
  - Large Z to max. pion production
  - Thin to minimize pion absorption
  - Minimize overall material in path of pions/muons
    - Mechanical supports, water lines, etc.
  - Preliminary thermal analysis complete.
    - Safety factor of 4
    - Benchmark calculations with prototype
  - Need a mechanical design, design of a water system, design of remote handling system to replace target

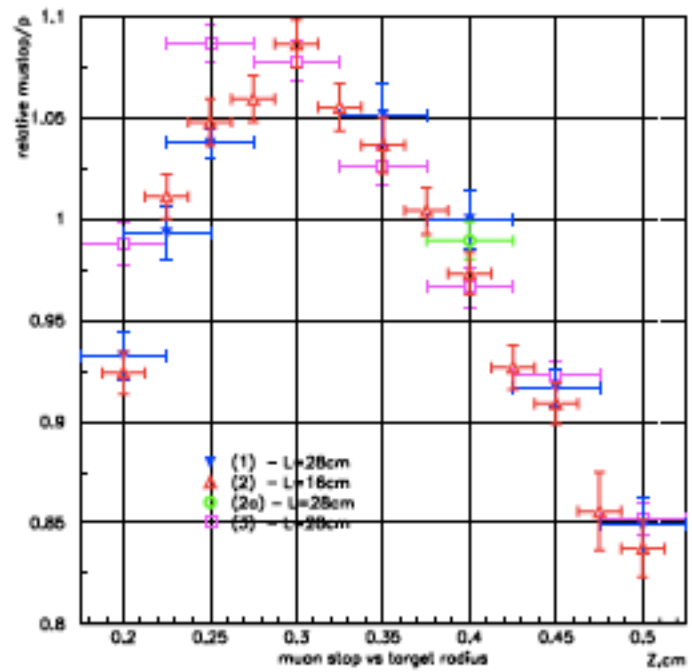
25 kW proton beam
2.2 kW ave. power in target
Design power load 8.6 kW



# Target Length and Radius optimization for best Stopped Muon Yield



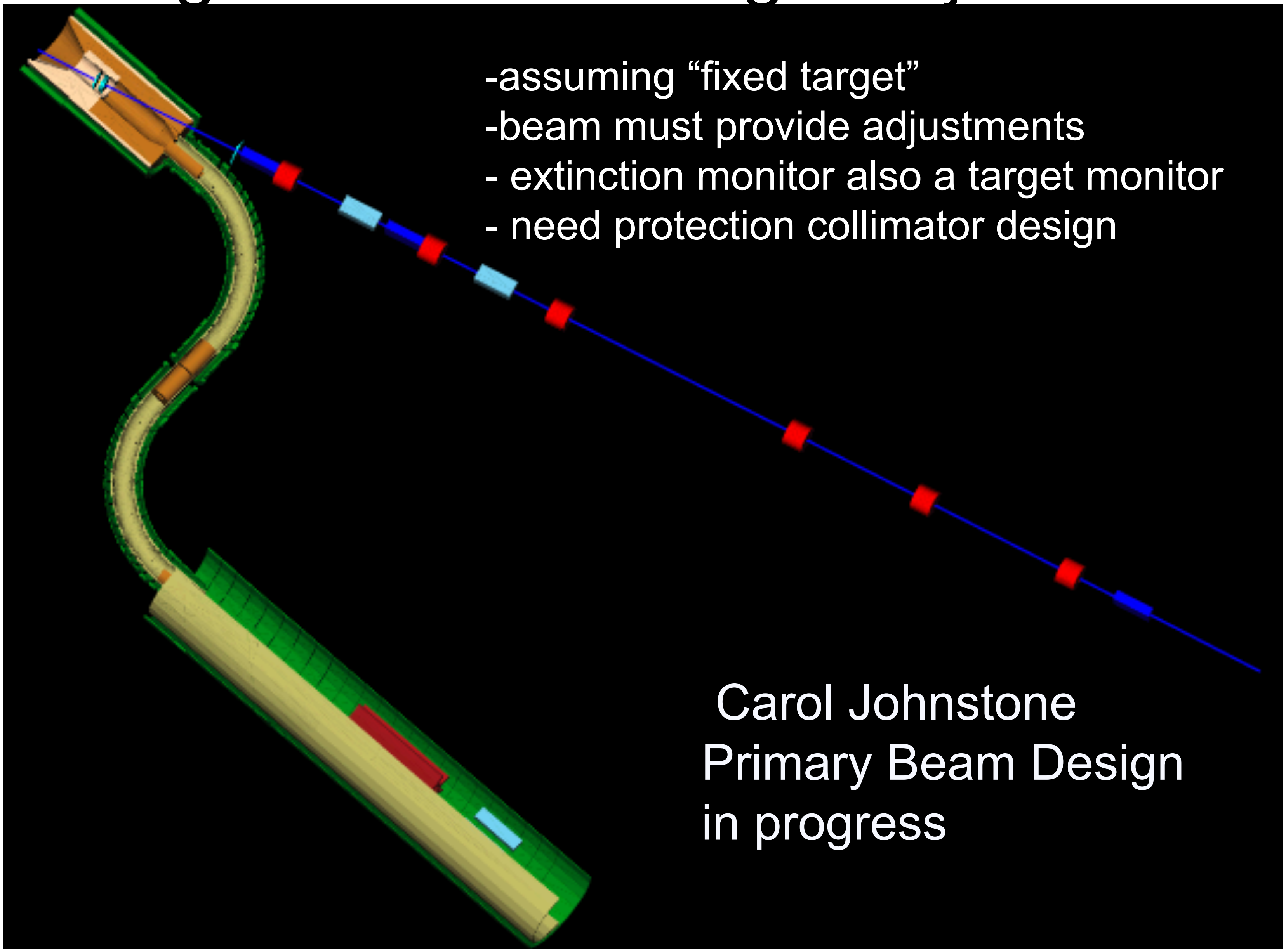

L(cm)




R(cm)

Need a well focused and controlled proton beam
$\sigma_{x,y}$= 1mm and position stability ~0.3-0.4 mm

# Target Position & Angle adjustment



# Effect of Water Cooling Plumbing on Muon Yield

| Inlet & Outlet Pipe OD (mm) | Inlet & Outlet Pipe wall thickness (mm) | Water Thickness (mm) | Ti target shell thickness (mm) | Relative Stopped Muon Yield |
|---|---|---|---|---|
| | | | | |
| None | None | 0.0 | 0.0 | 1.00 |
| | | | | |
| 3.2 | 0.1 | 0.2 | 0.15 | 0.97 +/- .015 |
| | | 0.3 | | 0.96 |
| | | 0.4 | | 0.94 |
| | | 0.5 | | 0.94 |
| | | | | |
| | | .25 | 0.2 | 0.96 |
| | | | 0.3 | 0.93 |
| | | | 0.4 | 0.94 |
| | | | 0.5 | 0.95 |
| | | | | |
| 11.5 | 0.76 | 0.5 | 0.3 | 0.82 |
| | | 2.35 | 0.76 | 0.73 |

Mechanical Support must give alignment of ~ 0.4 mm with minimal material

# Rutherford Appleton Laboratory (RAL) beginning Target Work

- Signing of Accord October 2010
- Task A : Analysis of the existing Mu2e production target conceptual design for the case of an off-center beam pulse – report February 2011
- Task B1: If Task A recommends continuing with existing design, then Conceptual Target support system- report June 2011
- Task B2: If Task A recommends exploring design alternatives, then conceptual design of target and supports- report September 2011
- Task C: Assuming the existing target design, conceptual design of water cooling system- report March 2011
- Task D: Remote handling system to replace target – report July 2011

# Next Talk Jim Popp- Target

- Extensive MECO studies on material, size, cooling, conceptual engineering
- Jim Popp was MECO collaborator, now Mu2e, will review in next talk
- Some more recent work on cooling done with Z. Tang

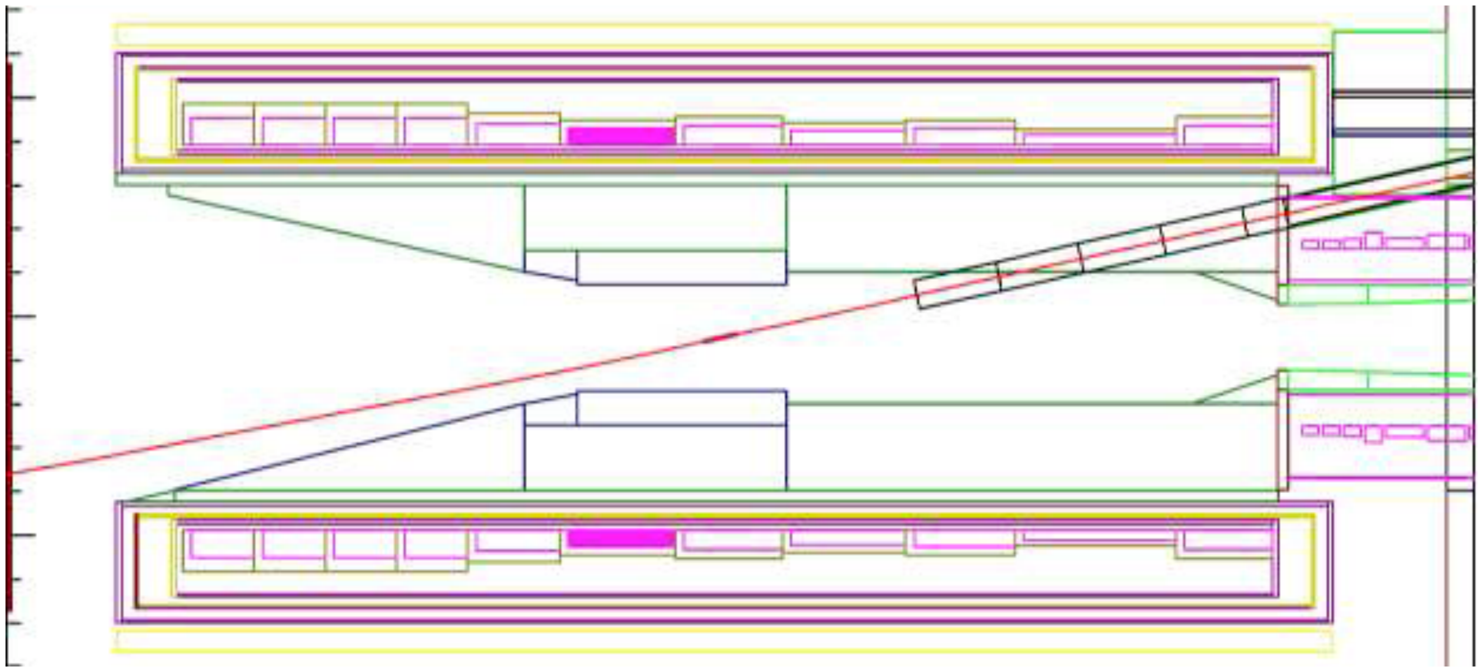
## Summary of Target Docs: Docdb

Copies available on request

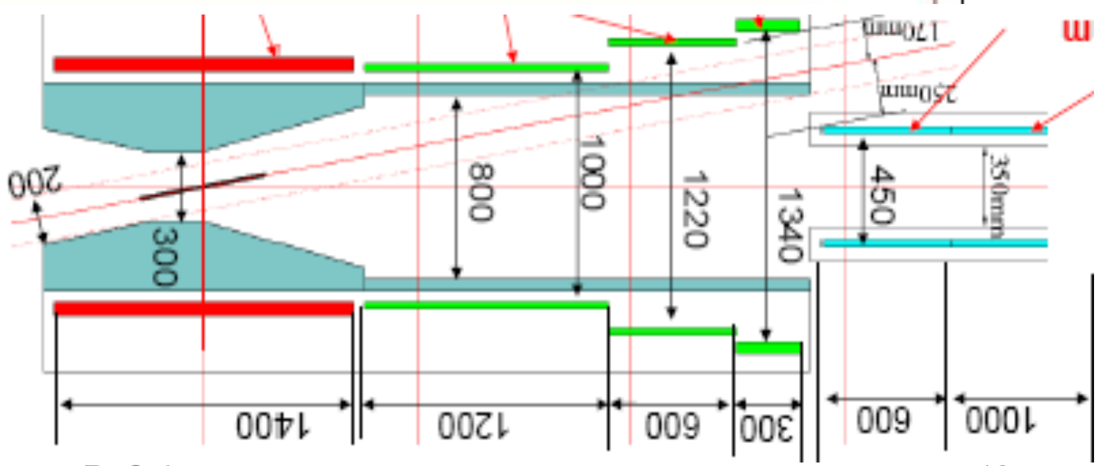
- 986-v1, **MECO Reference Design Document: WBS 1.3.1 Production Target**
- 985-v1, **MECO Production Target Research Summary**
- 887-v2, **Production Target Requirements**
- 796-v1, **Water-Cooled Pion Production Target Progress**
- 793-v1, **Water-Cooled Pion Production Target for the Mu2e Experiment**
- 739-v2, **Production Target Progress**
- 711-v2, **Radiation-Cooled Tungsten Target for Mu2e Experiment**
- 694-v1, **MECO Production Target Issues**
- 647-v1, **Thermal Stresses in Pion Production Target**
- 526-v2, **MECO Production Target Design**
- 195-v1, **MECO101 -- Heat Transfer Analysis of a Water-Cooled Production Target for MECO**
- 188-v1, **MECO094 -- Effect of Water Channel and Containment Shell Thickness on Muon Stopping Rates for the Water-Cooled Production Target**

# Re-evaluation of PS Length

MECO

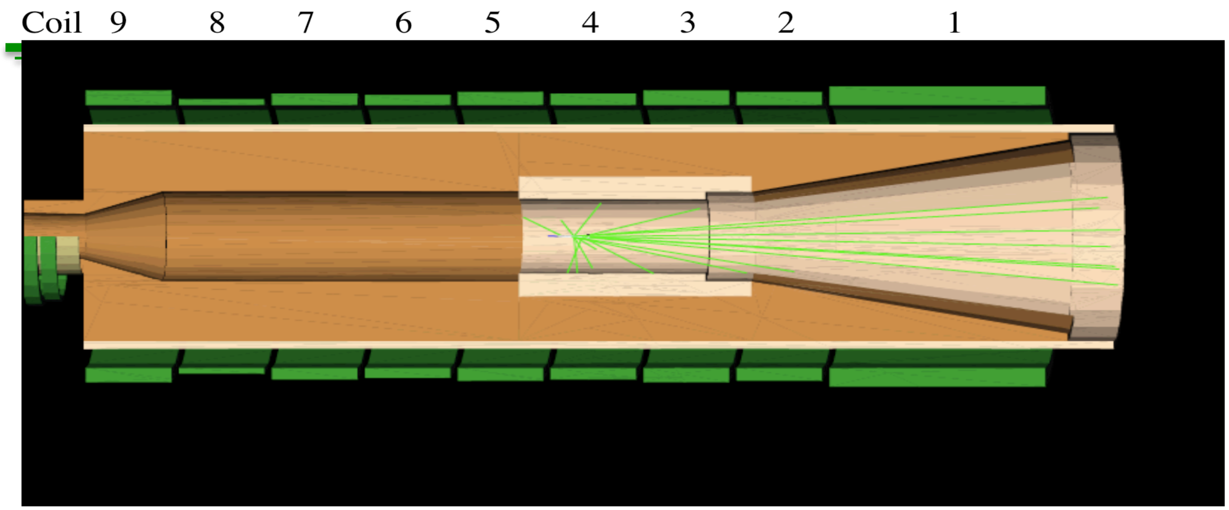


COMET

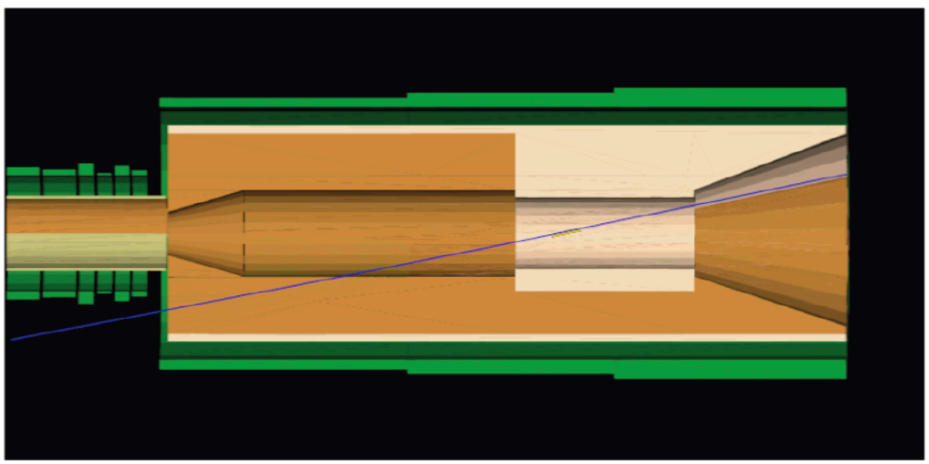



Jan 2009
Joint Mu2e/COMET workshop

# Production Solenoid Length Reduction




MECO
L=5.2 m



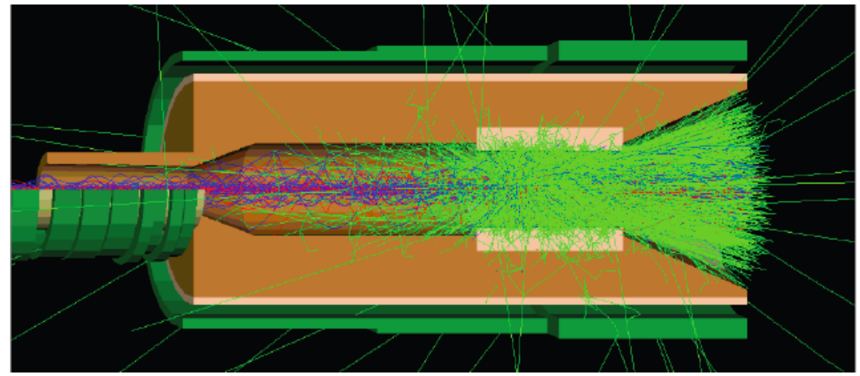
Mu2e
L=3.7 m

# Heat Shield

- Heat Shield
  - Protect the Production Solenoid.
  - Incoming proton beam is 25 kW
  - ~ 12 kW is absorbed into the heat shield

  - MECO design adequate for heat load in cold mass but MECO did not consider radiation damage to aluminum stabilizer.

  - Peak DPA in aluminum stabilizer is ~ 2.5 x $10^{-5}$/yr. Close to critical value at 4.2°K. Leads to rise in resistance which could lead to damage during a quench.
    - Al anneals with warm-up, but don't want to warm up more than once a year.
    - Better measurements coming soon

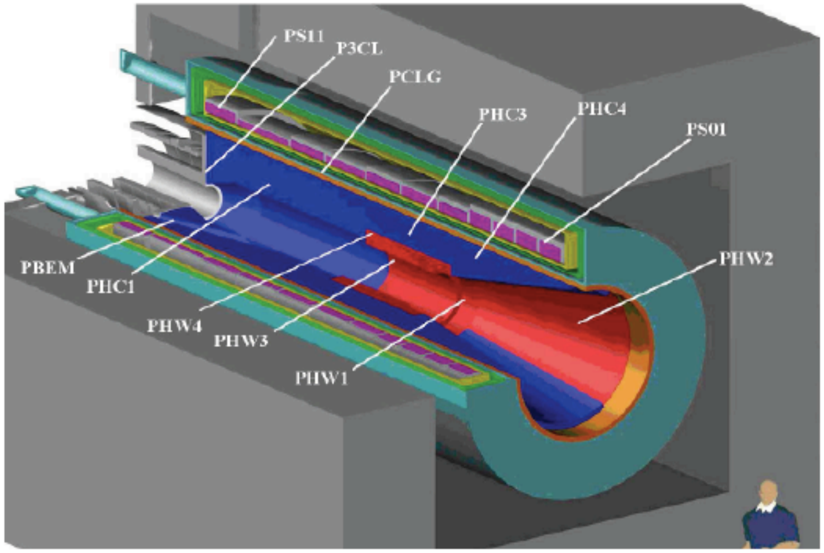


<100 W heat load coils
<15 $\mu$W/g instantaneous
< 350 kG/yr in coil epoxy

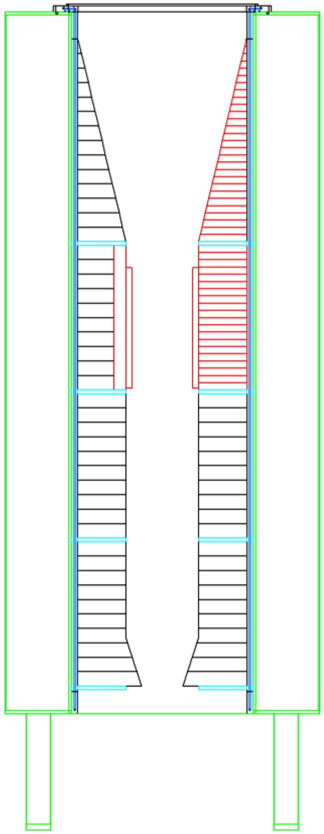
*MECO Solution*

*76 tons of Copper and Tungsten*

MECO-TGT -02-001 Heat&Rad. Shield Design

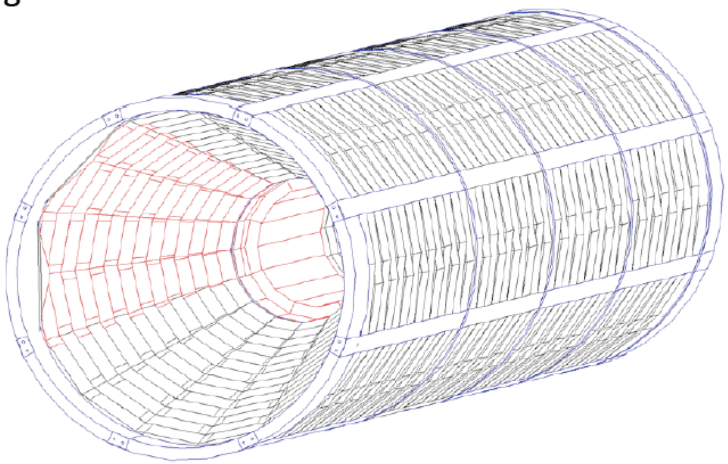


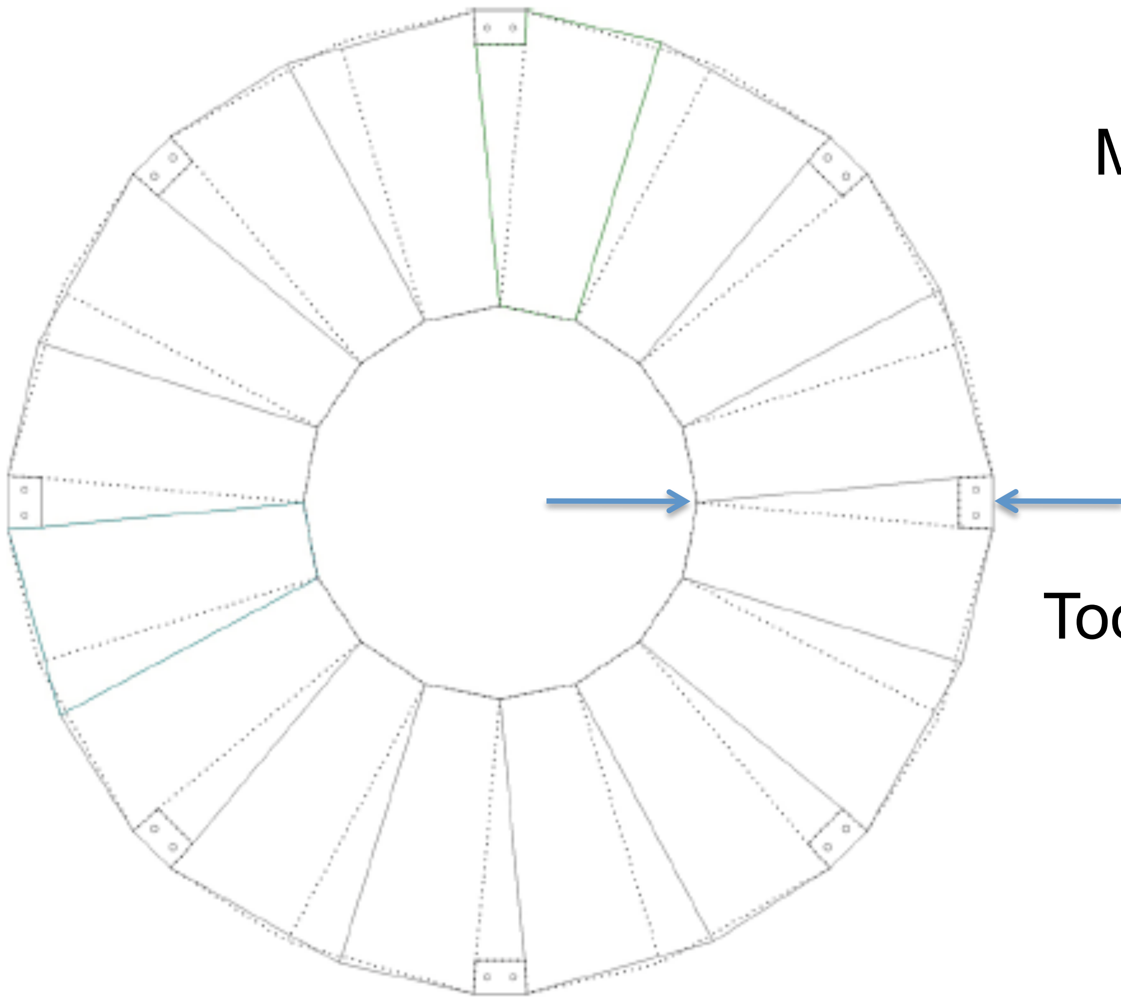

Diameter= 0.5 to 1.5 m
L= 5.5 m



## MECO solution meet specs but there were mechanical issues/questions

- Tungsten pieces too large
- Large number of pieces/machining…$
- Only conceptual engineering done – support, assembly, cooling





MECO

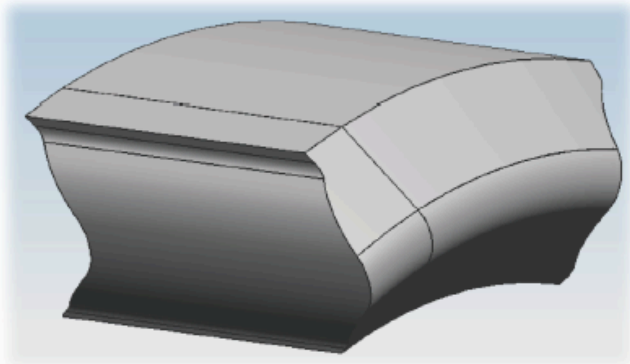
16-18”

Too Large for W

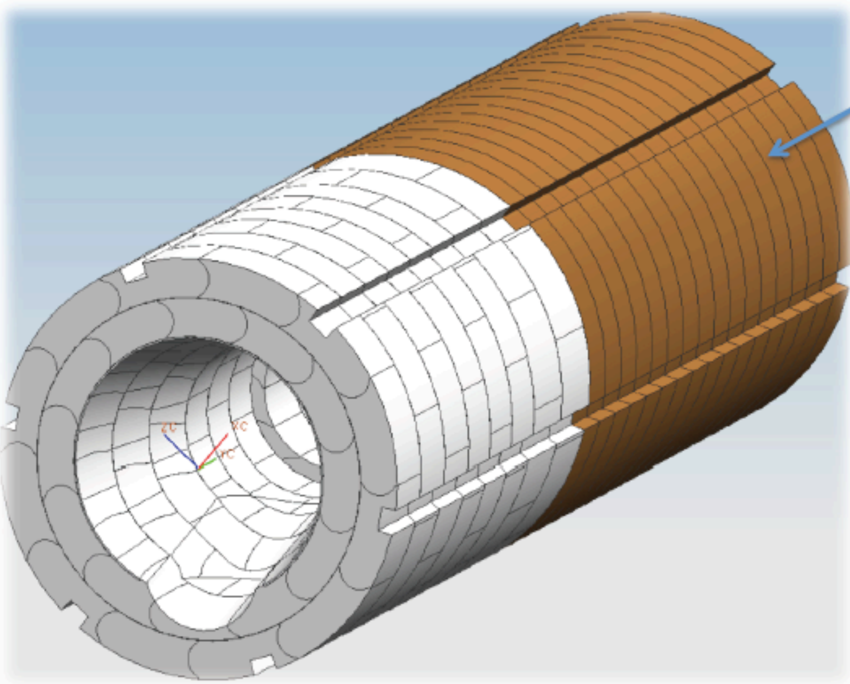
Thus maintaining a 5 K inlet to outlet temperature difference requires about 3 gallons of water per minute to remove the anticipated shield heat load.

# Mu2e Heat/Radiation Shield Update

Eric Rivera – Summer Intern
UIUC/GEM Mechanical Engineering Masters Student



Tungsten “brick” suggested by Allegheny Technologies (ATI)



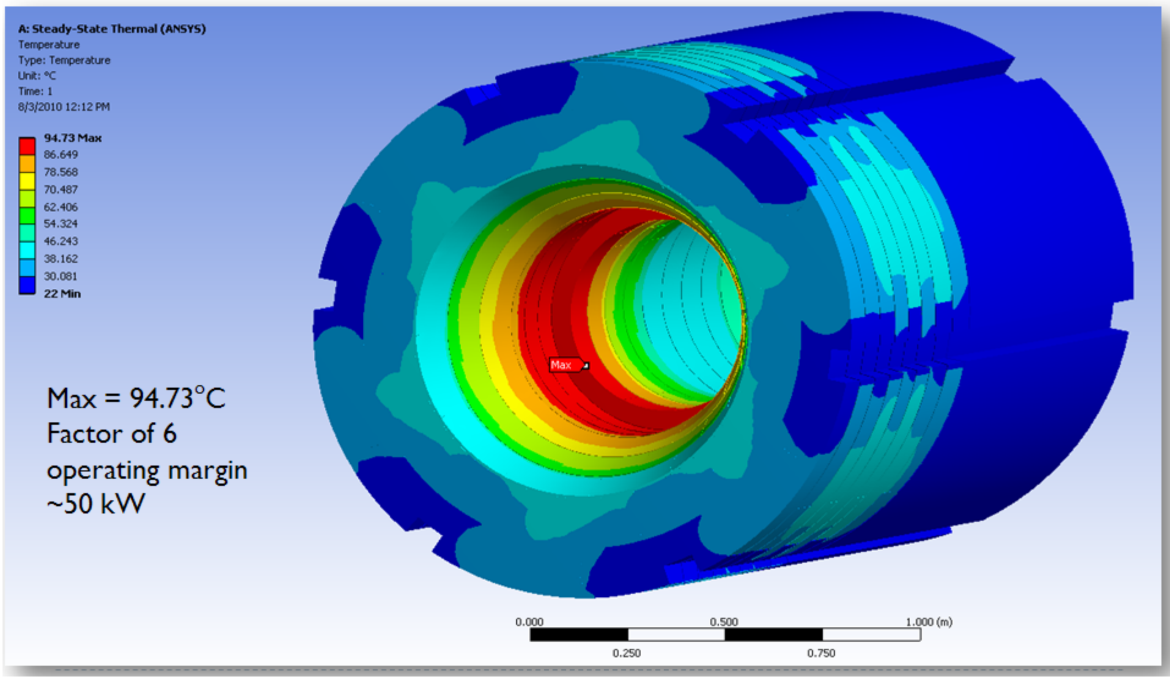
Copper rings welded-
Scott Forge and Weldaloy, Inc.

Premliminary Cost Estimate
~$1 M Copper
~$ 3-4 M for Tungsten

MECO had $3.5M

# ANSYS Thermal Analysis

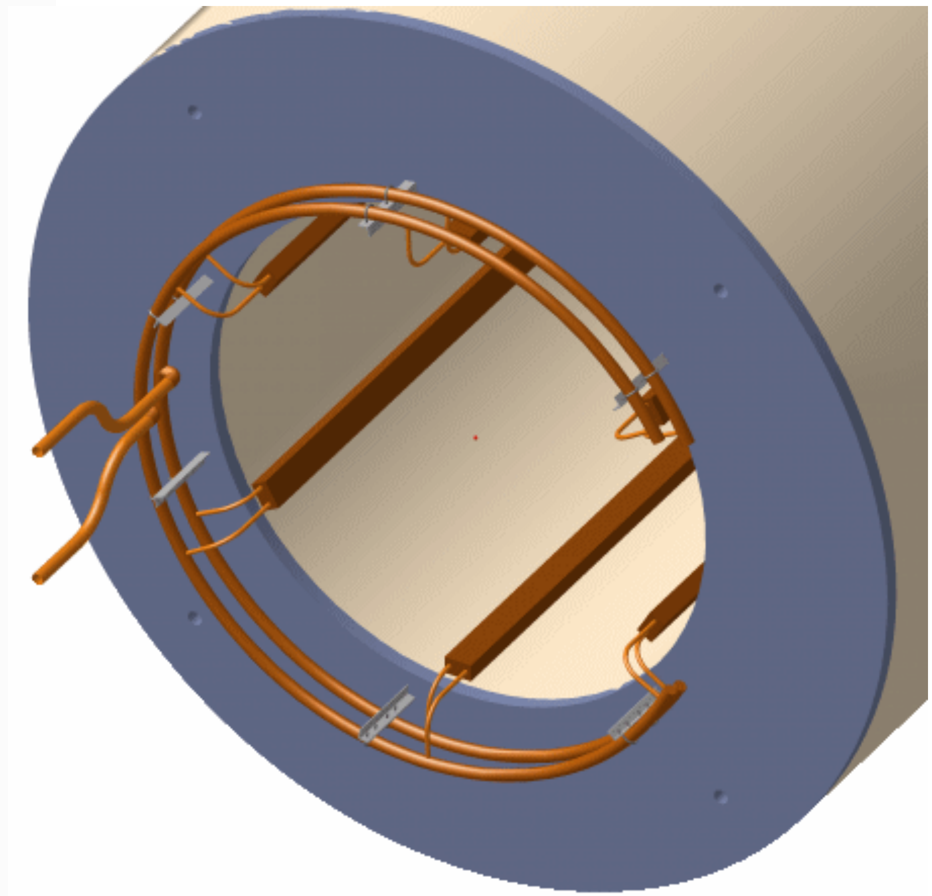
Thermal Analysis for ~50 kW - ANSYS



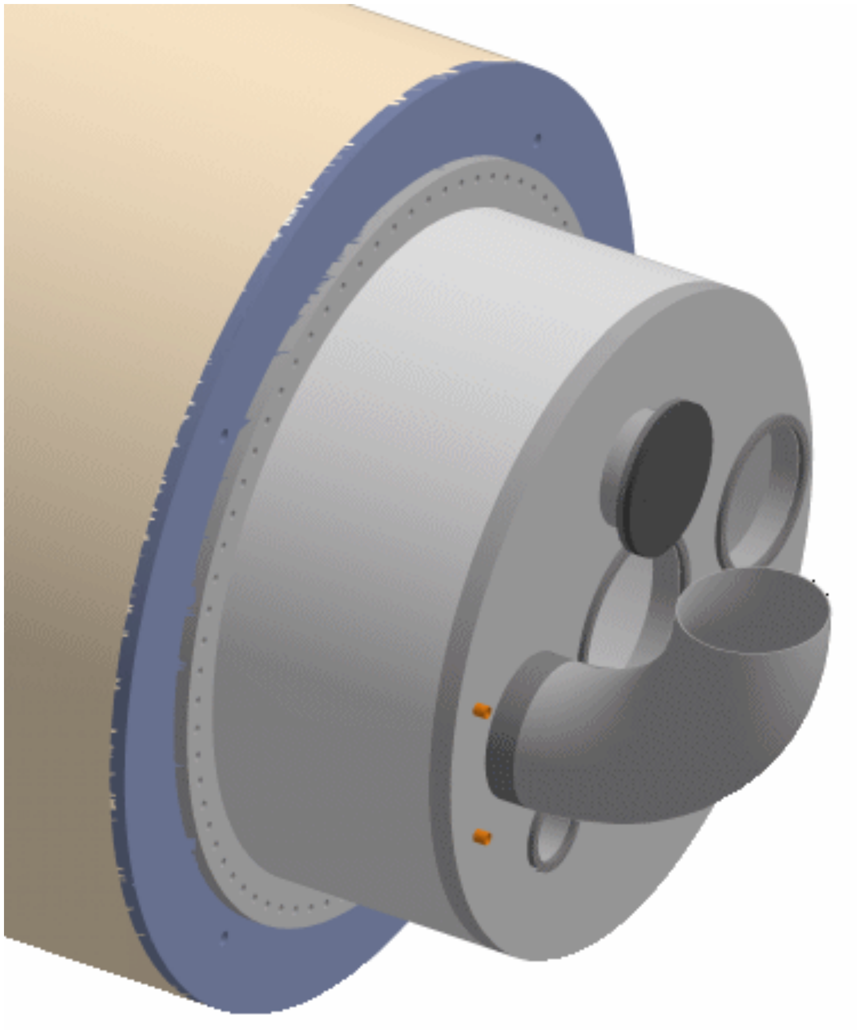

Eric Rivera

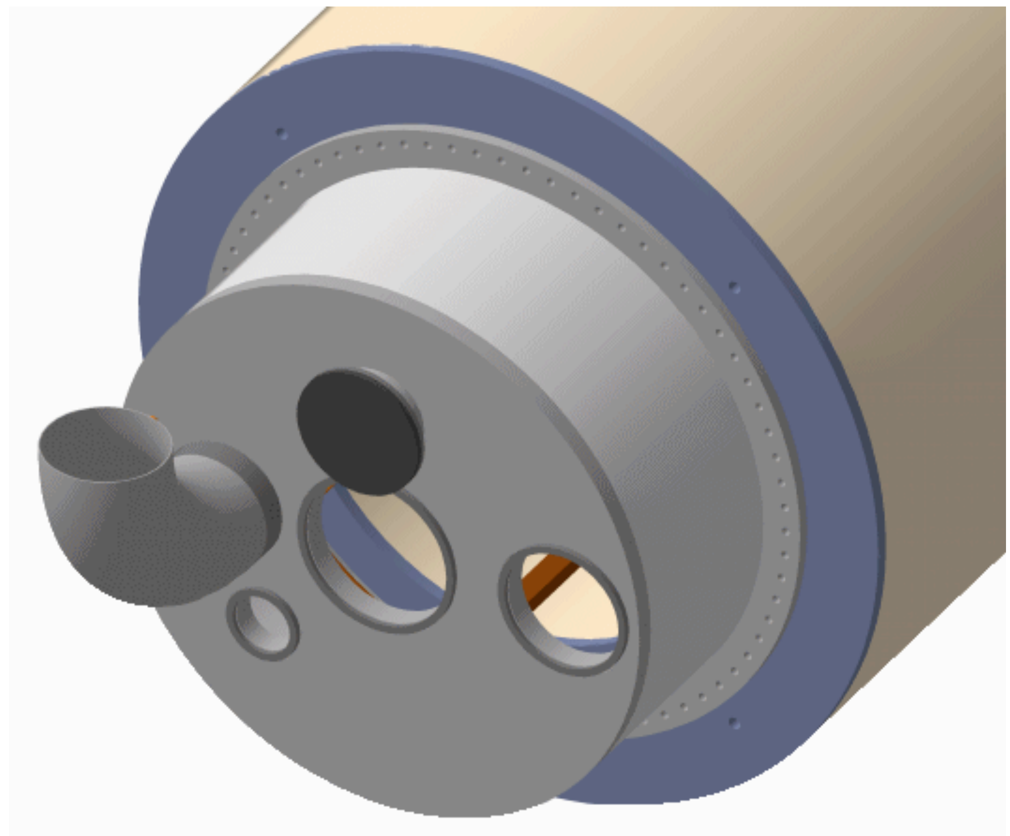
Assumes large operating margin (~5x), 0.2 mm air gaps
3 gpm water 1cm diameter pipe, Re=8E4 fully turbulent
Would need 63 kW to each channel to boil

# Heat Shield Water Manifold

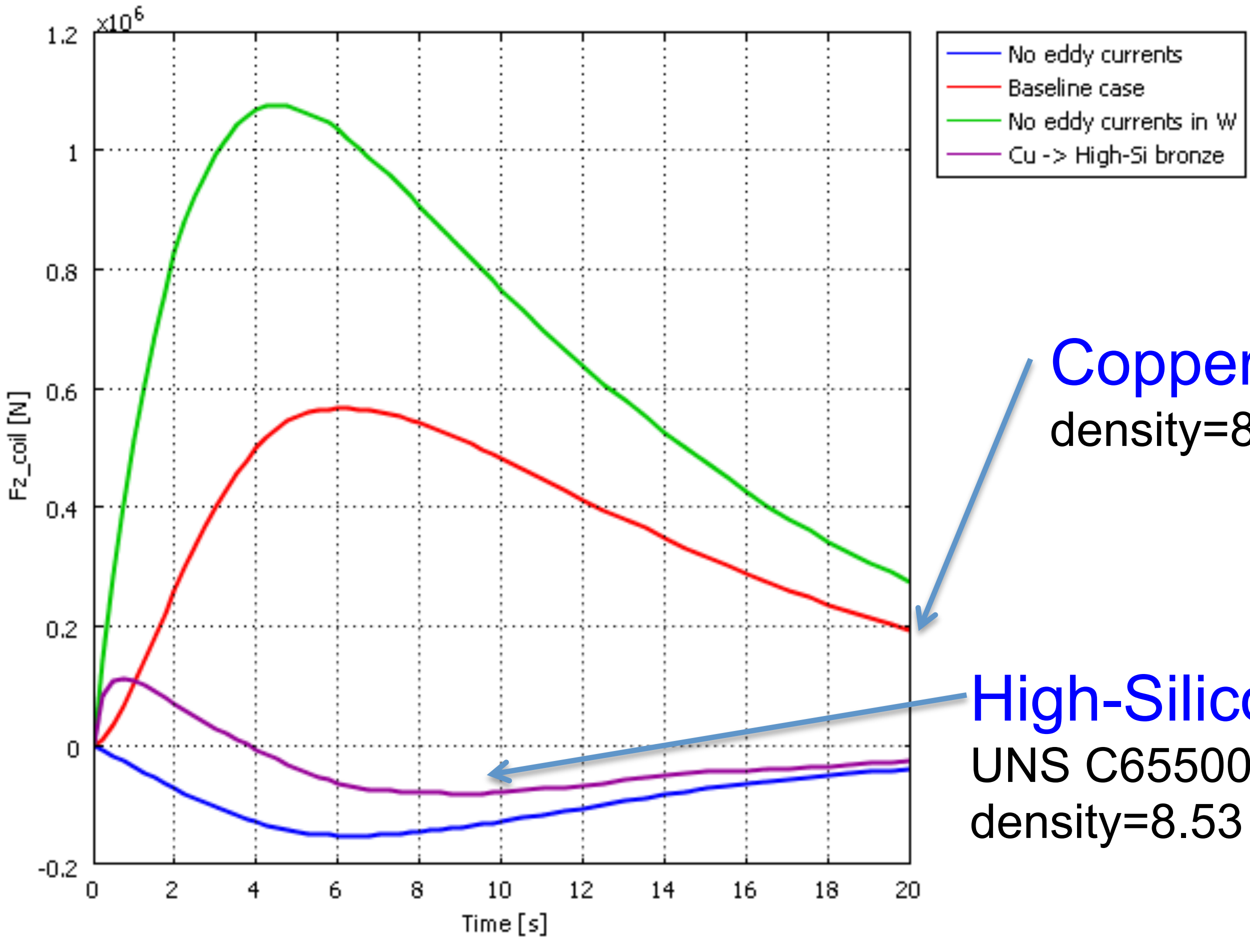


# Production Solenoid EndCap





# Axial Forces on Heat Shield During Quench => Replace Copper with Bronze




Vadim Kashikhin /TD

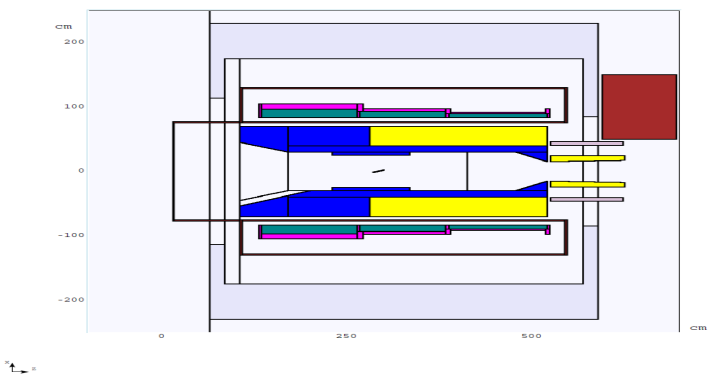
**Copper** ρ=1.7E-8 Ω·m
density=8.96 g/cc

**High-Silicone Bronze**
UNS C65500 ρ=2.46E-7 Ω·m
density=8.53 g/cc

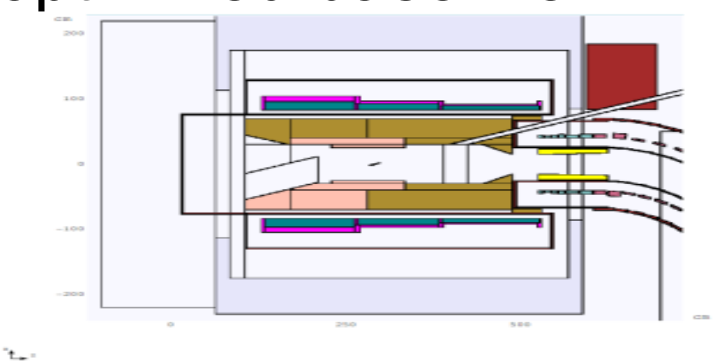
Axial Force nearly cancelled with Bronze +/- 10 tons

# 3D Thermal Analysis

- "baseline" ..2 months ago



- "optimized baseline"



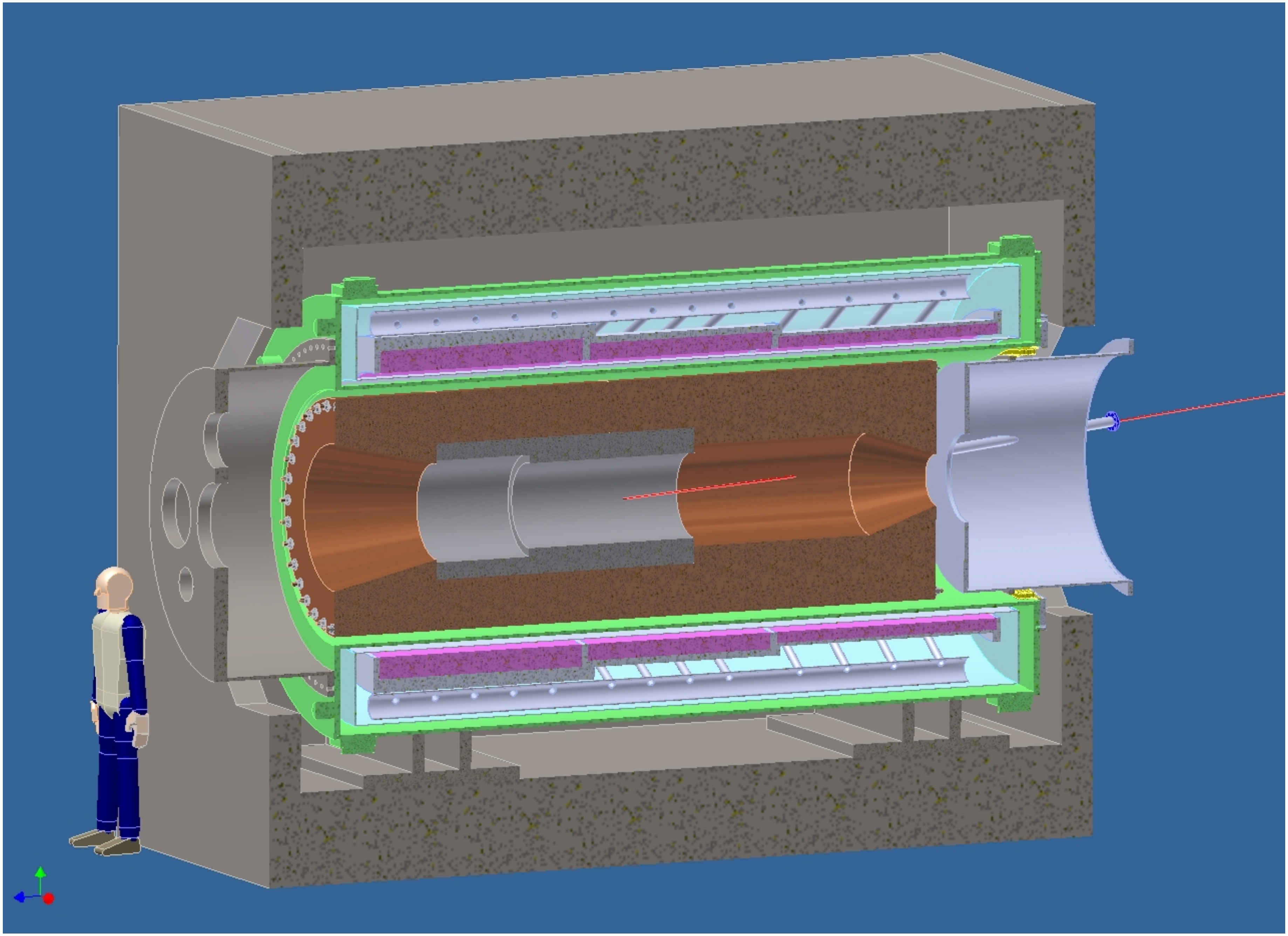
- Vitaly high statistics MARS run
- Vadim Kashikhin just finished
- "baseline" meets requirements(5x margin)

- "optimized baseline" is not done yet, very conservative scaling implies it falls short, may need more heavimet

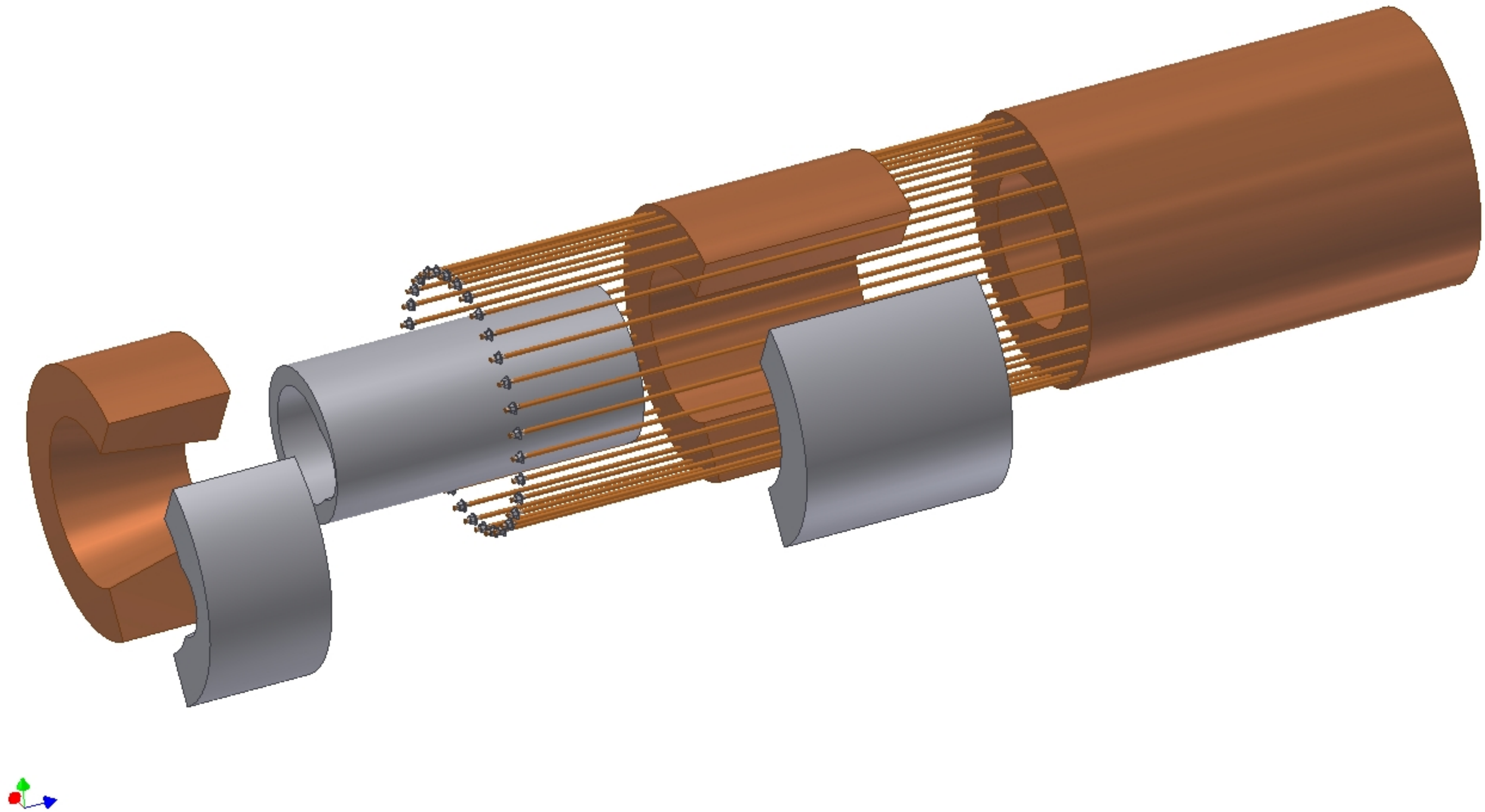
See Vitaly's talk for more detail

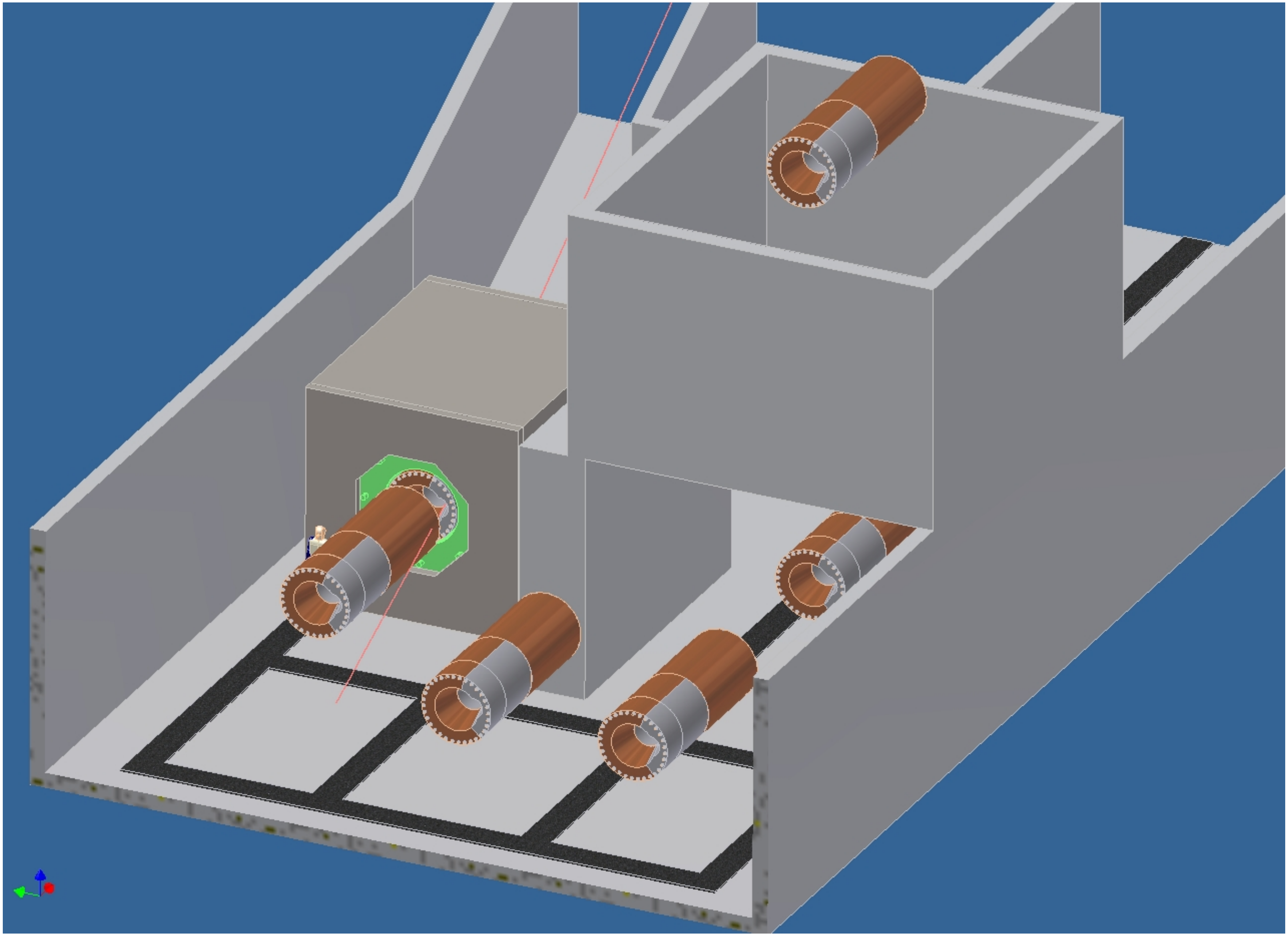
# Bartoszek Engineering beginning Heat Shield Work

- Signing of Accord October 2010- for heat shield design, assembly and installation
- Assembling CAD drawings including solenoids and heat shield
- Plans to visit tungsten vendor soon
- Considering possible methods of assembly (bolted)

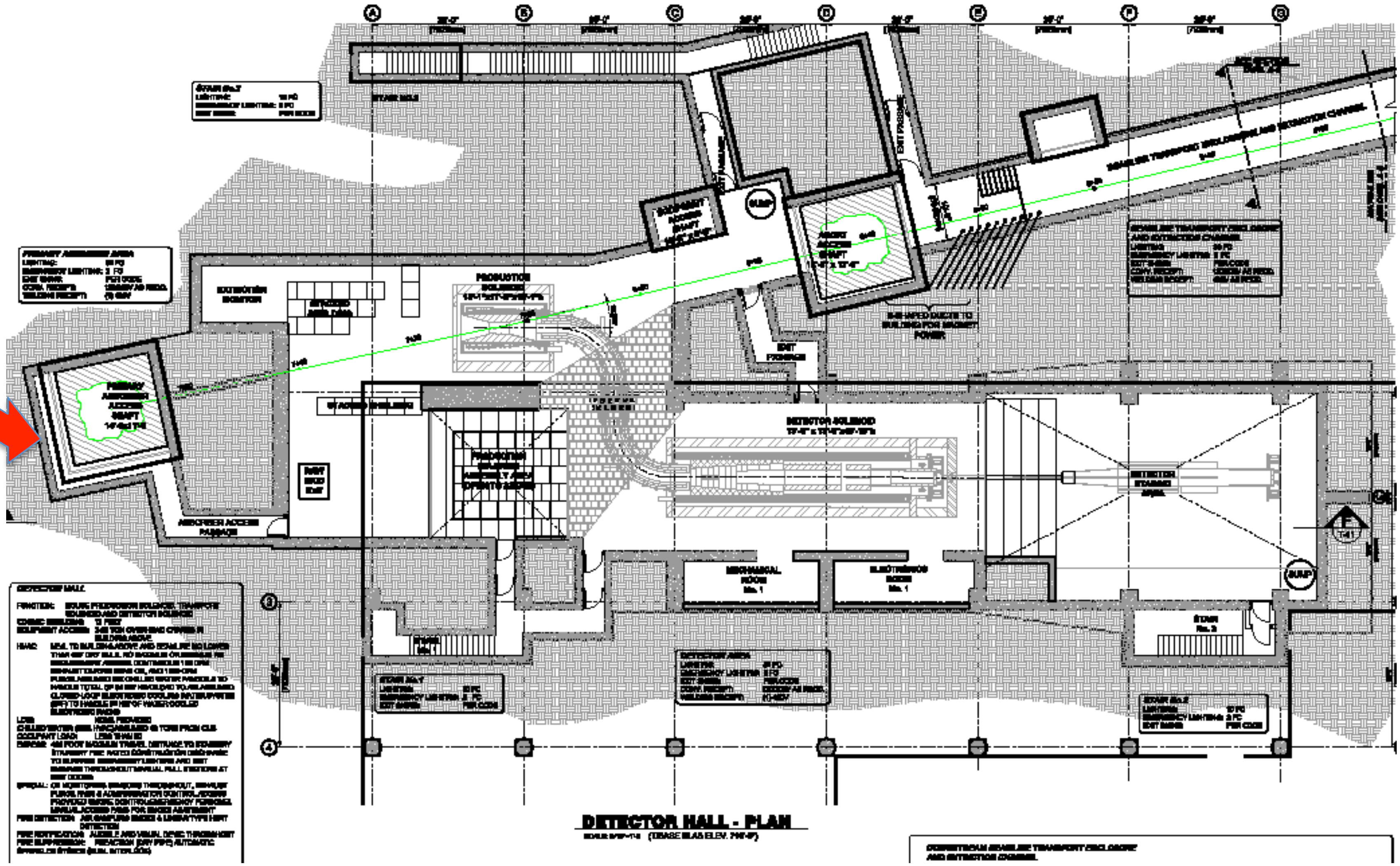


# Heavimet in grey, Si Bronze in brown

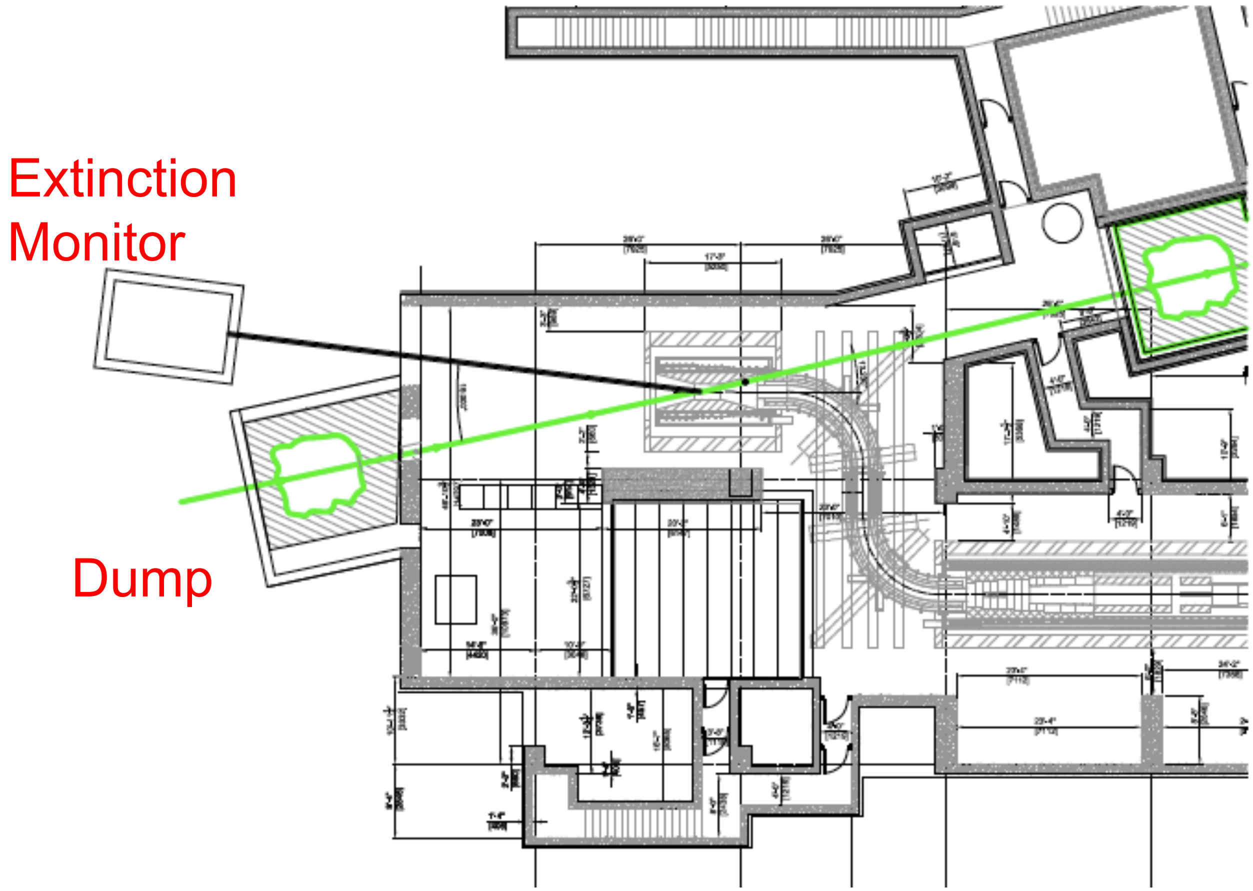




# Proton Beam Absorber



# Closer Updated View Proton Beam Absorber




Dump Design done (Vitaly), Optimization of shielding for Extinction Monitor just starting (P. Kasper-physics requirements)

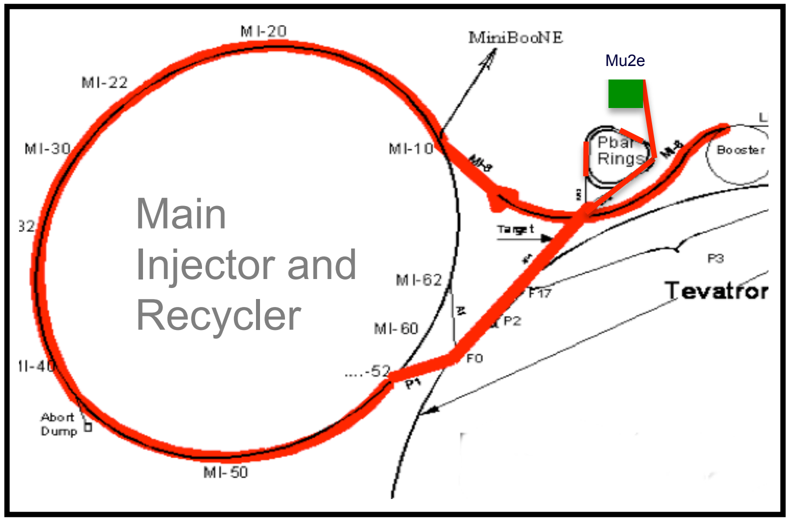
# Proton Beam Absorber

- Vitaly Pronskikh and Nikolai Mokhov have desiged a dump and done MARS calculations
- Bob Wands has done analysis on water flow requirements
- What is not done is working out the location of the extinction monitor and how it impacts the shielding/location of the proton beam dump

# Backup Slides

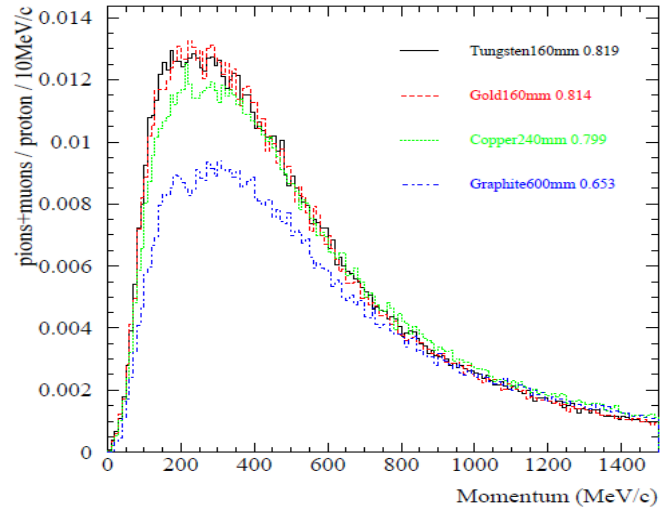
# Experimental Technique

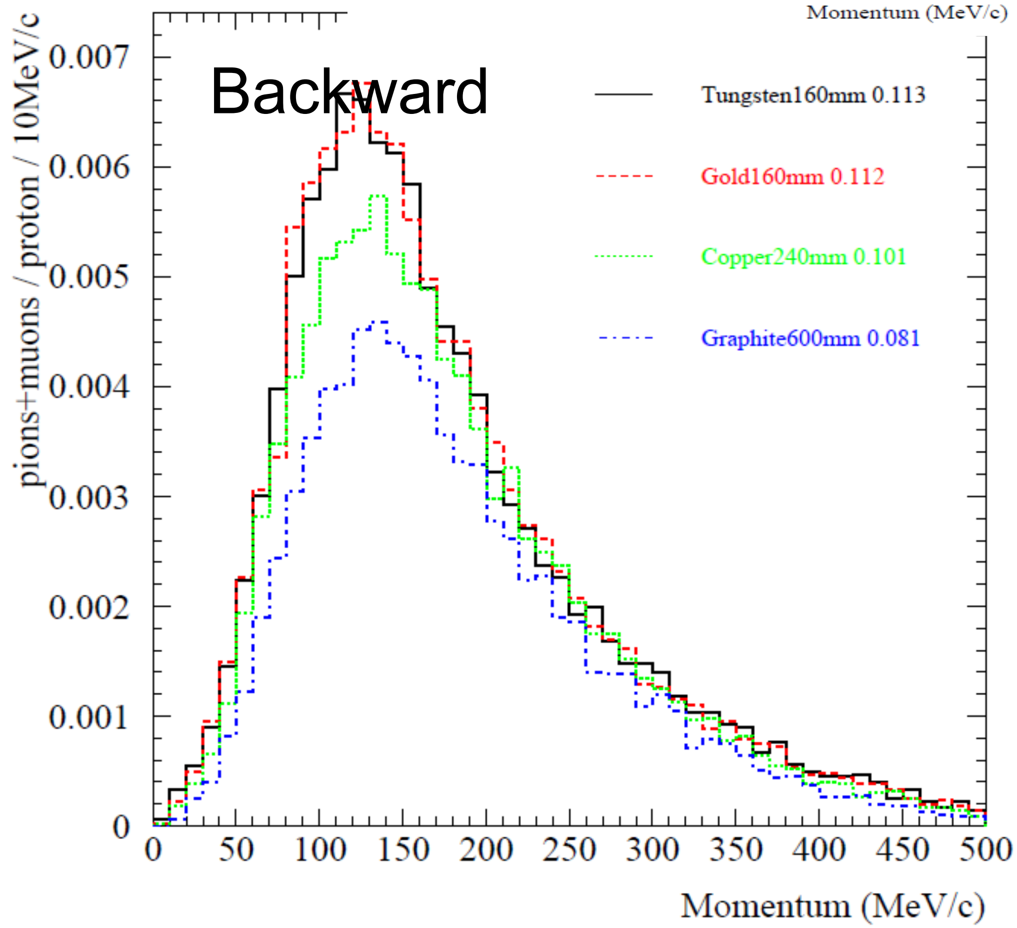
- Bring Booster beam into the Recycler, similar to NOvA, but kick it out into the P1 line and into the pbar Accumulator.
- Bunched in Accumulator Ring
- Slow spill from Debuncher to experiment.



# Pions at Target

- MARS simulation
- Count pions at target surface
- Compare momentum distribution for Tungsten, Gold, Copper and Graphite
- Heavy material has softer distributions

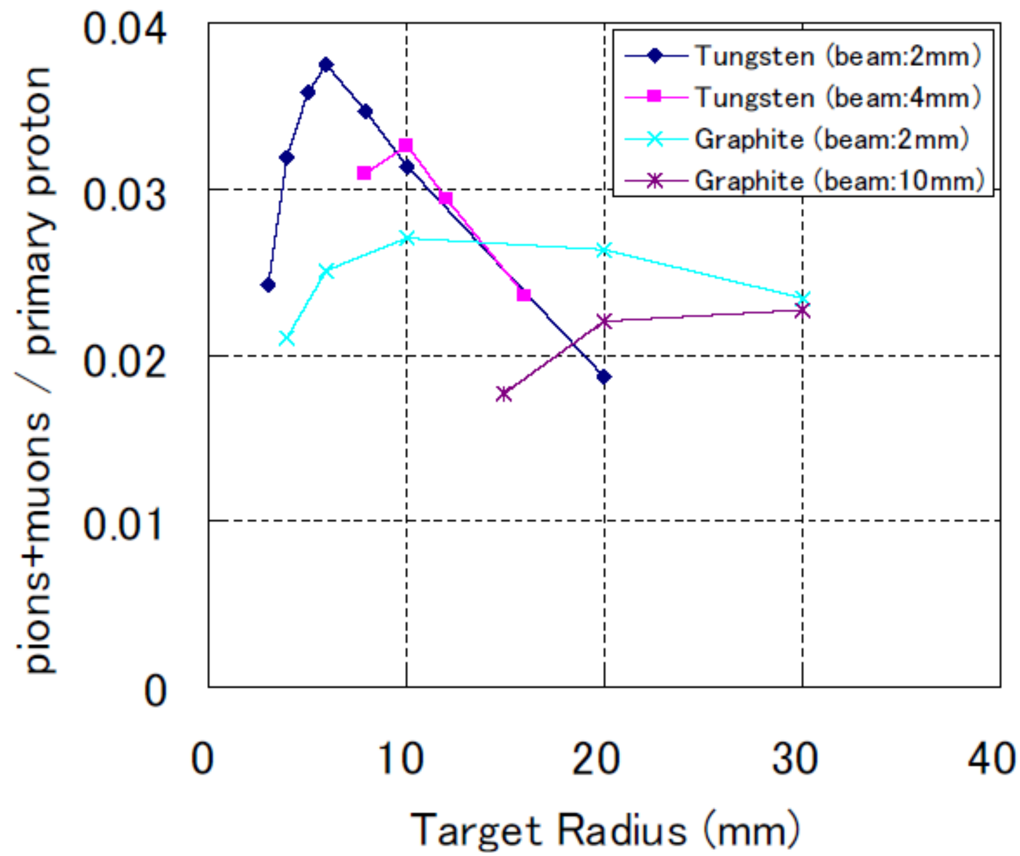


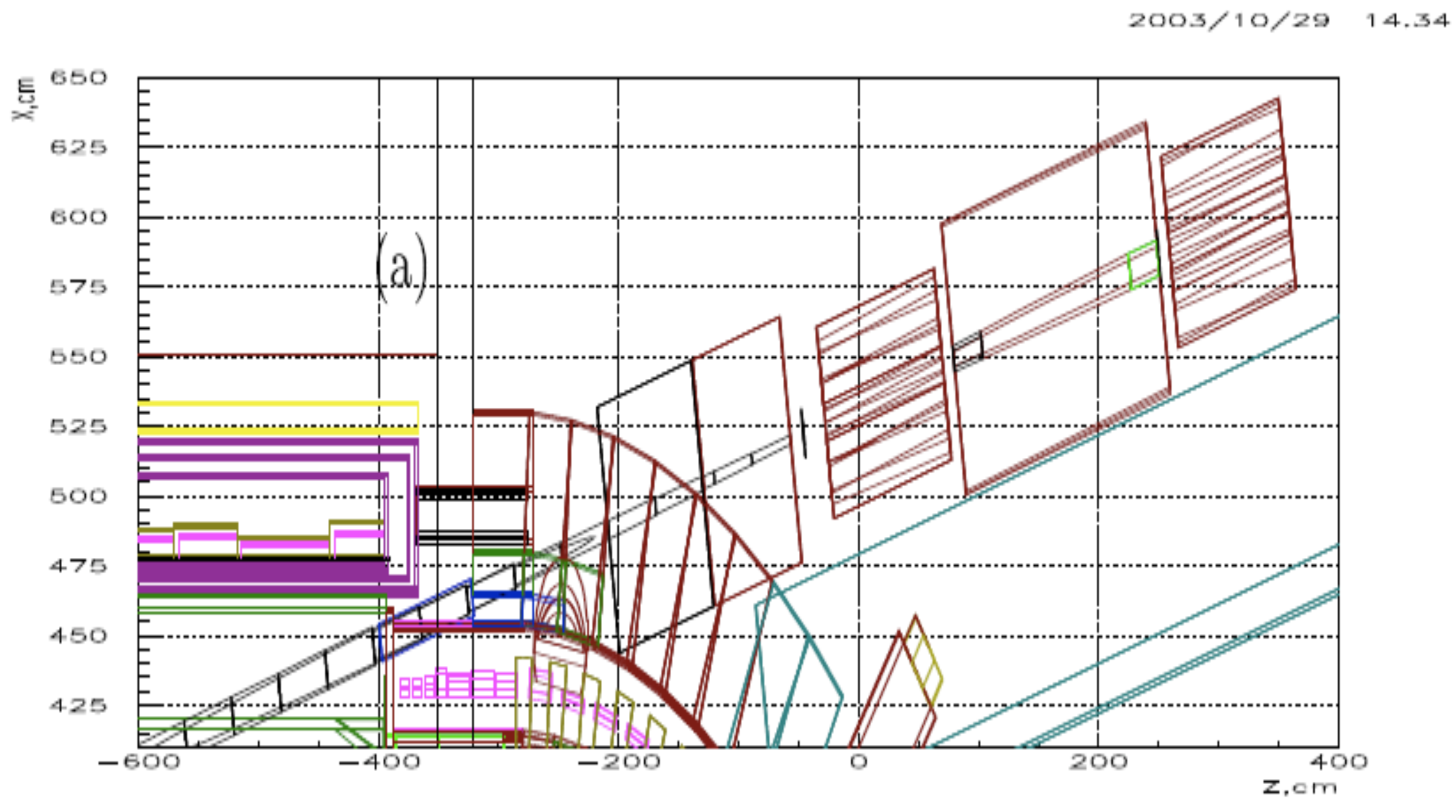

| | R (mm) | L (mm) | Backward (pions/proton) (P<0.5GeV/c) | Forward (P<1.5 GeV/c) |
|---|---|---|---|---|
| W | 6 | 160 | 0.113 | 0.819 |
| Au | 6 | 160 | 0.112 | 0.814 |
| Cu | 6 | 240 | 0.101 | 0.799 |
| Graphite | 20 | 600 | 0.081 | 0.653 |

# Target geometry

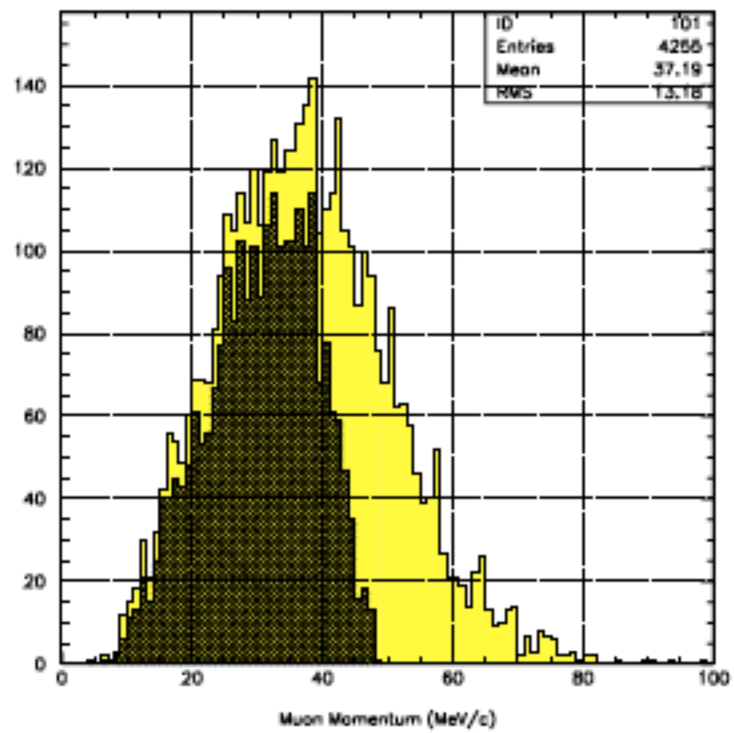
- Production and transport in MARS simulation down to 3m from target



# PS Protection Collimation

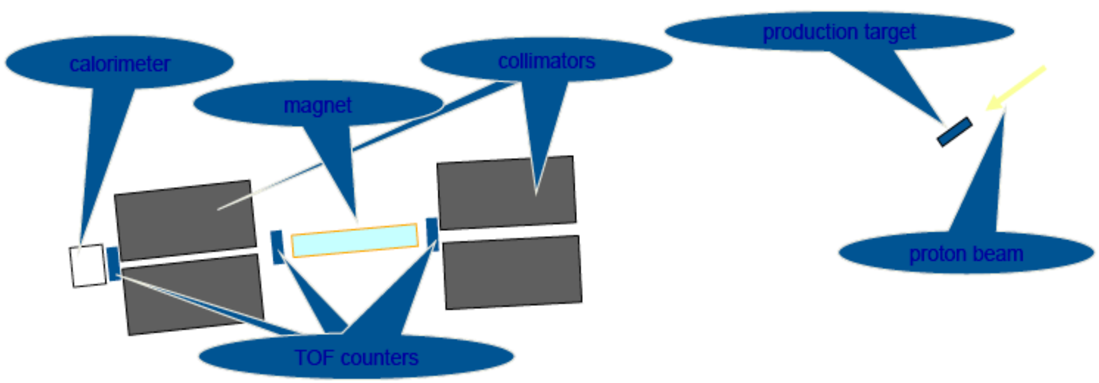


# Momentum of Muons to Detector



## Simulation and Schematic Diagram

- GEANT and GMC simulation for design, performance
  - Collimator bores ~1 cm diameter
  - Analyzing magnet 5 kG-m
  - With good shielding, contamination from low energy backgrounds are small




Schematic diagram illustration the method of measuring the proton extinction. Collimators A and B are identical with 1 meter long and 1cm aperture in radius. The magnetic dipole is 1 meter long and generates B field of 0.5 Tesla. Not drawn to scale.

Chuan Chen, UC, Irvine 05/15/2004 11

# Schedule

- Schedule has slipped due to slow start.